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Seasonal Changes in Scotopic Sensitivity

EDWARD J. SWEENEY,* JO ANN S. KINNEY, AND ALMA RYAN
U. S. Naval Medical Research Laboratory, New London, Connecticut

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The scotopic sensitivity of three subjects was tested weekly over the course of a year. In addition, two measures were made to indicate each subject's amount of exposure to sunlight. Scotopic sensitivity was found to be poorest in the summer months, when exposure to sunlight was greatest, and to increase gradually during the fall and winter. The course of sensitivity over the year agreed well with the external measures of exposure to sunlight, the best single measure being the amount of "blue" light reflected by the skin.

INTRODUCTION

SHORT term effects of light exposure on dark adaptation have been extensively explored in relation to the duration and intensity of the pre-illumination. If the pre-adapting light is varied in intensity or duration, differential effects on dark adaptation curves may be observed, but after thirty or forty minutes in darkness, the differences among different curves have been reduced to nothing, or effectively that.

In addition to these short term effects of light exposure, there are various studies indicating that prolonged exposure to high intensities of light may have effects that persist for several hours, or even several weeks, and that only by measurement over a long period can the limiting sensitivity characteristic of an individual be established. In a wartime study by Hecht, Hendley, Ross, and Richmond,[1] it was found that exposure to bright sunlight over a period of a few weeks led to a general lowering of night vision that persisted one or two weeks. Clark, Johnson, and Dreher[2] used prolonged occlusion of one eye and exposure to bright sunlight of the other, and found differences in night vision sensitivity between the eyes that persisted at least 18 hrs. Furthermore, Peckham[3] has shown that excessive exposure to sunlight impairs visual acuity and CFF at low photopic and mesopic levels of illumination.

There seems to be little question that long term effects of exposure to sunlight can occur. The present investigation was undertaken to establish the extent to which such long term shifts do occur in the course of a year, for individuals going about their normal activities in the northern temperate zone. These prolonged effects will be of importance to the testing of night vision sensitivity since, if seasonal shifts occur, an individual's score on such a test would not be comparable with scores of other men taken at other times.

APPARATUS AND PROCEDURE

The Night Vision Sensitivity Test developed at the Medical Research Laboratory was used in this study.[4–6] Individual scores can be determined with this apparatus, which, for untrained subjects, have a test-retest reliability of 0.83.

The observer is presented with points of light against a totally dark surround at twelve locations in his visual field. These lie at 5, 10, and 20 deg above, below, to the right, and to the left of a central fixation point. The intensity of the points of light is constant at approximately 5.0 log$\mu\mu$L. Their size[7] is varied in equal steps from 0.07 to 0.34 deg of visual angle; these sizes are given the arbitrary designations of 1 to 10 and are referred to as test units.

The general testing procedure consisted of presenting four sizes, in a random order, so that each of the twelve positions was sampled once with each size. Two spots were shown on each trial, and the subject reported the location of each spot in relation to the fixation, as "Up," "Down," "Right," or "Left." The stimulus sizes used in each session were varied according to the individual's sensitivity on that day, yielding liminal values in terms of size. The entire procedure was repeated in each session of testing so that two liminal values, each based on 48 judgments, were obtained for each subject on the same day. Thirty minutes of dark adaptation was given prior to the testing, so the sensitivity measurements refer to a period in which the person approaches his limiting sensitivity for the given session.

Scotopic sensitivity determinations were made each Wednesday on three subjects from August of the first year through August of the second year. During this time, each subject completed 50 sessions; 44 of these were on the same day for all three subjects.

* Now at Life Insurance Agency Management Association, Hartford, Connecticut.

[1] Hecht, Hendley, Ross, and Richmond, M&S Research Project No. X-442 (Av-233-w) Medical Field Research Laboratory, Camp Lejeune, North Carolina, (1945); Am. J. Ophthalmol. 31, 1573 (1948).

[2] Clark, Johnson, and Dreher, Am. J. Ophthalmol. 29, 828 (1946).

[3] R. H. Peckham and R. D. Harley, Am. J. Ophthalmol. 34, 1499 (1951); R. H. Peckham and W. J. Arner, J. Opt. Soc. Am. 42, 621 (1952).

[4] Fooks, Sweeney, and Dimmick, "Pilot studies of a scotopic sensitivity test." Naval Medical Research Laboratory Report No. 285 (June 1957). (Available at NMRL, New London, Connecticut.)

[5] Sweeney, Kinney, and Ryan, "Standardization of a scotopic sensitivity test," NMRL Report No. 308 (March, 1959).

[6] Kinney, Sweeney, and Ryan, "A test of night vision sensitivity," Am. J. Psychol. 73, No. 2 (June, 1960).

[7] For the interrelations of the size, brightness, and color temperature of the source in determining thresholds, see de Groot, Dodge, and Smith, NMRL Report No. 234 (1953), and J. S. Kinney, J. Opt. Soc. Am. 46, 1093 (1956).

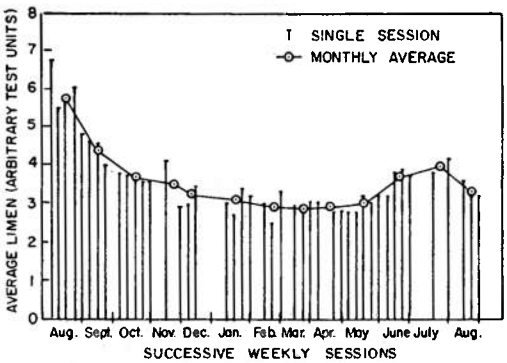

FIG. 1. Monthly and single session average scotopic sensitivity of three observers.

Two methods were used to obtain an indication of the individual's exposure to sunlight. First, each subject kept a daily diary of his exposure to direct sunlight, to the nearest half hour. No attempt was made to obtain excess exposure to sunlight; the subjects simply kept track of the amount of time spent in the sun which, in the summer, included occasional days at the seashore.

Second, measurements were made of the reflectance of the skin of the observers to show the amount of "tan" acquired, and thus, have another indication of the amount of exposure to sunlight. The skin area above the person's nose was chosen since it would be exposed in much the same manner as the eyes. Measurements were made with the Photovolt reflectometer, Model 610; this instrument is equipped with three filters, "red," "green," and "blue," by which the percent reflectance of these various colors can be obtained.[8] All three filters were used in this experiment, the "green" one to give the absolute percent of light reflected from the skin, and the "red" and "blue" to show whether the relative reflectance of the two colors changed during the course of the year. The search unit, which in this instrument is about 2 in. diam and is at the end of a flexible cord, was placed directly on the forehead to obtain the measures.

TABLE I. Variation in scotopic sensitivity from session to session and from first to second determination in the same session.

	Variation in scotopic sensitivity (test units)							
	Within sessions			Between sessions				
Obs.	Sum of squares	df	Variance	Sum of squares	df	Variance	F ratio	Correlation ratio
JK	8.339	50	0.1668	145.524	49	2.9699	17.805	0.97_2
AR	3.258	50	0.0652	57.790	49	1.1794	18.089	0.97_2
PK	4.108	50	0.0822	74.670	49	1.5239	18.539	0.97_3

[8] These filters are the standard tristimulus filters supplied with the instrument. They have transmission curves that are nearly symmetrical and have peaks at 438, 552, and 595 mμ. Tristimulus values can be obtained from the reflectance readings found by using these filters; these values, however, are not reported in the present study since the simple percent reflectance readings gave the desired information.

RESULTS

The main results of this investigation are presented in Fig. 1. There were 44 sessions in which all three observers had been tested on the same day, and the mean limens for these observers, along with the monthly average of these values exhibit a steady decline (indicating increased sensitivity) from August to February. By May, increases in liminal values are noticeable, and these continue through July. The cycle is not symmetrical, however, in that sensitivity is not as poor the second summer as the first. If the curves for the individuals were plotted they would all look similar to the curve in Fig. 1 although they do not show necessarily the same degree of seasonal change.

Table I gives a comparison of the size of the differences in limens within a single session and between the sessions for each individual subject. Here, it can be seen that in each case the variation in limens from session to session is much larger than that within a session. The F ratio of these variances shows that this difference is highly significant. The large values of the correlation ratio are another way of expressing the size of this seasonal effect.

TABLE II. The differences in sensitivity among the three observers according to their rank in 44 sessions.

	Observer		
	JK	AR	PK
Sum of the ranks	110.5	95.5	58.0
Av. rank	2.51	2.17	1.32
Coefficient of concordance		0.378[a]	

[a] Sign. <0.01 level.

The extent of seasonal change can be expressed also in terms of the variation in sensitivity among individuals. This type of representation is relevant to the issue of the feasibility of a night vision test. If an individual's scotopic sensitivity changes very greatly over the year, he might be found more sensitive than another person at one time, and less sensitive on another occasion. That this possibility is very real, appears when the variations among individuals are computed. Pooling the available sessions, it is found that the estimated individual difference variance is 0.3726 test unit.[9] This is considerably smaller than the variation of the given individuals over the year shown in Table I. An individual is, thus, likely to be more similar in scotopic sensitivity to another person measured at the

[9] In another study (see reference 5) over 100 enlisted men had their scotopic sensitivity determined during fall and winter. The variance among them represents individual differences, but is also somewhat inflated by seasonal effects and by greater unreliability in the measurements. Even so, this variance is 1.21 test units, still smaller than the seasonal variation of our three observers over the entire year.

same time, than he is to himself measured at a different season.

This does not mean that individuals do not have characteristic scotopic sensitivity, some being typically more sensitive than others. Even among our three observers, the inter-observer variance is considerably larger than the within session variance in Table I. If the individuals are ranked within each session in terms of scotopic sensitivity, there is some consistency over the year, the lowest person tending to maintain this position throughout. Table II gives the results of ranking the three subjects according to their scotopic sensitivity in each session. Kendall's Coefficient of Concordance,[10] obtained from the ranks, is also given and is a measure of the consistency with which each subject maintained his rank. This value is easily significant beyond the 0.01 level. Thus, the fact of real individual differences, which a night vision test might measure, cannot be questioned.

The prospects for a night vision test can be improved if it is possible to measure the history of sunlight exposure of the individual apart from his scotopic sensitivity. Several measures were included in the present investigation with this object in mind. Table III presents correlations between scotopic sensitivity and three types of measures: length of day, report of sunlight exposure, and skin tanning. For all three observers, the best single correlation is found for the blue filter in determination of skin tanning.

TABLE III. Correlation of scotopic sensitivity with various other measures for each of three observers. $N=50$.

Measure correlated with scotopic sensitivity		Observer JK	AR	PK
Time of Sun Set		0.40	0.23	0.35
Prior Sunlight Exposure	Half week	0.27	0.36	0.48
	Whole week	0.36	0.32	0.40
	Two weeks	0.40	0.36	0.41
Skin Reflectance	Blue filter	−0.52	−0.79	−0.65
	Green filter	−0.40	−0.61	−0.62
	Amber filter	−0.34	−0.41	−0.61
	Sum of three filters	−0.42	−0.58	−0.64

In Figures 2, 3, and 4, respectively, monthly average data for two weeks prior sunlight exposure, time of sunset, and "blue" skin reflectance are superimposed on the monthly average scotopic sensitivity curve of Fig. 1. The similarities are striking, especially for the skin reflectance reading. In fact, if the scotopic sensitivity curve had behaved symmetrically, as it was expected to, the two functions might be completely congruent.[11]

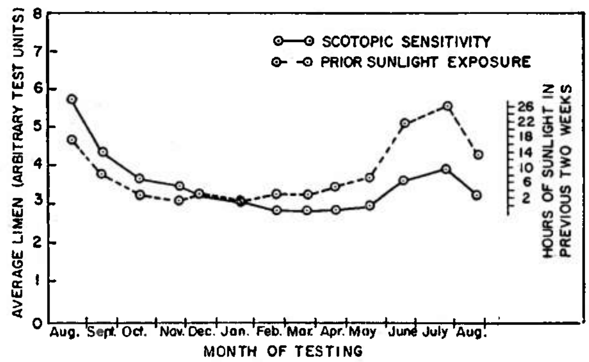

FIG. 2. Monthly averages for three observers of prior sunlight exposure and scotopic sensitivity.

It may be asked if some combination of these measures might predict scotopic sensitivity better than any one of them alone. Intercorrelations between time of sunset, the blue filter reading, and exposure to sun were computed and used to obtain multiple correlations between scotopic sensitivity and various combinations of the sunlight measures. Although some improvement was obtained in individual cases, the over-all increase in the correlations found was not enough to be of practical importance.

DISCUSSION

In the now classic studies of the effect of the intensity and duration of the pre-illumination on dark adaptation, extreme conditions of pre-exposure have been used to show the magnitude of the effect, ratios being of the order of 1000 to 1.[12,13] Also, in the studies done to show the long-term effects of bright sunlight on scotopic sensitivity, the individuals were commonly subjected to excessive amounts of sunlight, having normally screened from sunlight. The largest value obtained in any session for an individual, on the skin above the ridge of the nose, fell short of 25, and it can be seen in Fig. 4, that the monthly averages range only between 15 and 21.

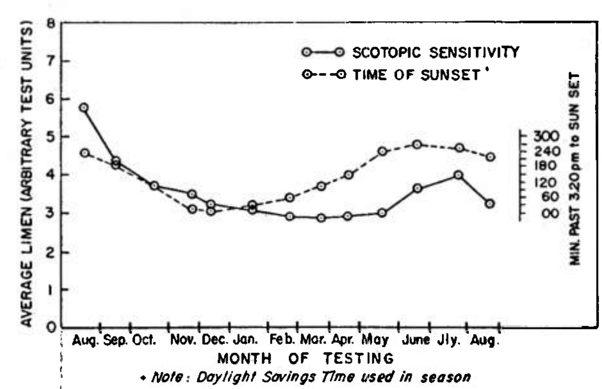

FIG. 3. Monthly averages for three observers of time of sunset and scotopic sensitivity.

[10] M. G. Kendall, *Rank Correlation Methods* (Hafner Publishing Company, New York, 1955), second edition, p. 95.

[11] It may be of incidental interest to note the reflectance of untanned skin with the blue filter. Values of 30, 36, and 39.4 were obtained for three observers, measured on a portion of skin

[12] Hecht, Haig, and Chase, J. Gen. Physiol. **20**, 831 (1937).

[13] F. A. Mote and A. J. Riopelle, J. Comp. Physiol. Psychol. **46**, 49 (1953).

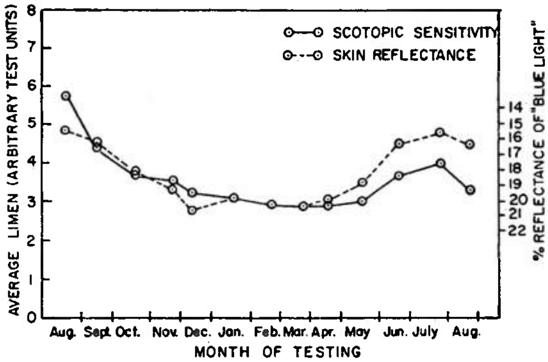

FIG. 4. Monthly averages for three observers of skin reflectance and scotopic sensitivity.

spent, for example, long periods of time at the beach or in the desert. It has been demonstrated here that this effect does not depend upon excessive amounts of exposure to sunlight, but is found in individuals going about their normal activities during the seasons.

Furthermore, the magnitude of the seasonal effect, although undoubtedly less than what it would be under extreme conditions, is of sufficient size to be of great importance in night vision testing. Berry[14] has summarized the wartime work on night vision tests, illustrated many of the failures, including unreliable results and poor cross-validation studies, and pointed out some of the reasons for the failures. To this list must be added the seasonal effect demonstrated here. If the amount of difference in an individual's night vision sensitivity is as great from season to season as the normal differences between individuals, then no night vision testing can succeed that does not take this into account.

Since individual differences do exist in addition to this seasonal variation, the problem becomes one of evaluating the individual's sunlight exposure in addition to testing his night vision sensitivity. Several means were tried in this experiment and others are no doubt conceivable. The simple expedient of crediting a man tested in the summer with the average difference between winter and summer scores would undoubtedly help.

It is also interesting to note that sizable amounts of exposure to sunlight stop around the first of September, yet the increase in scotopic sensitivity for all observers continues for several months beyond that time. A similar statement is true for the reflectometer readings; that is, recovery of a high proportion of reflectance or whiteness of the skin is a slow process that takes at least two months after significant exposure stops. Thus, scotopic sensitivity and skin reflectance, for an individual, are highly correlated and their recovery processes are closely parallel, a fact which can certainly be used to evaluate sunlight exposure in testing night vision sensitivity.

In this connection, it is interesting to speculate that scotopic sensitivity might be improved further by prolonged periods of restriction from exposure to light. The possibility is suggested by the large difference found between the untanned and tanned skin even in winter; if the courses of recovery of scotopic sensitivity and skin reflectance run parallel, there is room for great improvement in the former case. One instance can be cited in this regard. Berest, Curveillé, and Perdriel[15] reported that a group of subjects who spent all their daylight hours under dim light in a scope room, had excellent night vision. They attributed this to the effect of the continued restriction of exposure to light. The idea certainly deserves further experimentation under controlled conditions.

In view of the results of the various measures of sunlight exposure, all of which returned to the same level the second summer as they were the first, one would expect to find a symmetrical curve for scotopic sensitivity too. Various explanations could account for the fact that sensitivity was not as poor the second summer as the first, but no definitive answer can be given. The test materials might have been overlearned or the exposure to sunlight different, if sun glasses, for example, were used more one summer than another. One possible explanation, that of the practice effect commonly found in naive subjects, does not seem applicable in that these subjects had had a great deal of experience with the test itself and had participated in at least 50 sessions before this particular experiment began.

CONCLUSIONS

Scotopic sensitivity was found to vary seasonally with the amount of exposure to sunlight, being poorest in the summer months and best during the winter and early spring. The amount of seasonal variation for a given individual was as great as the normal differences found between individuals, although significant individual differences still exist at any given season.

External measures of exposure to sunlight also showed a similar seasonal change. The highest correlation was found between scotopic sensitivity and the amount of "blue" light reflected from the skin, scotopic sensitivity becoming gradually better as the amount of light reflected gradually increases.

[14] W. Berry, "Review of wartime studies of dark adaptation, night vision tests, and related topics," Armed Forces-NRC Vision Committee (December 1, 1949).

[15] Berest, Curveillé, Perdriel, "Les normes d'aptitude visuelle des lecteurs de scope," Médecine Aéronaut. 13, No. 3, 265 (1958).